Rapidity losses in heavy-ion collisions from AGS to RHIC energies

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Abstract.

We study the rapidity losses in central heavy-ion collisions from AGS to RHIC energies with the mean rapidity determined from the projectile net-baryon distribution after collisions. The projectile net-baryon distribution in the full rapidity range was obtained by removing the target contribution phenomenologically at forward rapidity region from the experimental net-baryon measurements and taking into account the projectile contribution at backward rapidity region. Based on the full projectile net-baryon distributions, calculation results show that the rapidity loss stops increasing from the SPS top energy to RHIC energies, indicating that baryon transport does not depend strongly on energy at high energies.

1. Introduction

The ultimate goal of studying (ultra-)relativistic heavy-ion collisions is to search for the signatures of possible quark-gluon plasma (QGP) formation and explore the properties of QGP and the phase transition from hadronic matter to de-confined quark matter [1, 2, 3, 4]. In heavy-ion collisions, the colliding nuclei lose part of their kinetic energy for the possible formation of QGP and new particle production. The degree of kinetic energy loss is customarily quantified by the average rapidity loss,

$$< \delta y >= y_p - < y_b >, \tag{1}$$

where y_p is the rapidity of the projectile before the collisions and $< y_b >$ is the mean rapidity of projectile net-baryons after the collisions [5, 6]. However, experimentally it is not possible to distinguish between baryons originating from the target or from the projectile. Thus, phenomenological models have to be used in order to extract the pure projectile net-baryon rapidity distribution from experimental data.

Rapidity losses in heavy-ion collisions were measured at different energies from AGS, SPS to RHIC [7, 8, 9, 10] with aims of determining the degree of nuclear stopping and energy density built up in the reaction zone. At AGS energies, it was demonstrated by the E917 collaboration that the net-baryon distributions after heavy-ion collisions

could be well described with double gaussians [7]. The mean rapidity losses were then correctly estimated by using Eq. (1) with the $< y_b >$ determined from the gaussian centered at positive rapidity, which was assumed to correspond to the projectile baryon distribution. At SPS and RHIC energies the mean rapidity losses were calculated without distinguishing the origin of the net-baryons but the mean rapidity value from the mid-rapidity to y_p was taken as the $< y_b >$ [8, 9, 10]. This makes the comparison of rapidity losses at different energies complicated when the contribution of target baryon to the net-baryon distribution at the rapidity region above mid-rapidity showed a strong energy dependence [10]. In order to study the energy dependence of the rapidity loss, it is thus necessary to examine the sensitivity of rapidity loss value to the target baryon contribution.

In this paper, we first extract in section 2 the pure projectile net-baryon distribution from experimental measurements of net-baryon distributions based on phenomenological model descriptions of target baryon contribution to the net-baryon yields at positive rapidity in the center-of-mass system. Then we calculate the average rapidity loss in the most central heavy-ion collisions at different energies with the obtained pure projectile net-baryon distribution and show its energy dependence in section 3. Finally, we conclude with a short summary in section 4.

2. The projectile net-baryon rapidity distribution

The projectile baryons peak at y_p before the heavy-ion collision, while after the collision the projectile baryon distribution can extend from target rapidity to the projectile rapidity [6]. Thus, to obtain the average projectile baryon rapidity $< y_b >$ after the collision, the integration should be carried out from the target rapidity to the projectile rapidity. For symmetrical heavy-ion collisions, we express the $< y_b >$ in the center-of-mass system as

$$< y_b >= \frac{2}{N_{\rm part}} \int_{-y_p}^{y_p} y \frac{dN^{B-\bar{B}}}{dy} dy, \tag{2}$$

where $\frac{dN^{B-\bar{B}}}{dy}$ is the projectile net-baryon rapidity distribution and $N_{\rm part}$ is the number of participating baryons in the collisions. In collider experiments one can choose any of the two incoming beams as the projectile. In this paper, we consider the nuclear beam in positive rapidity direction as the projectile.

As it is experimentally impossible to distinguish baryons originating from the target or from the projectile, one has to rely on phenomenological models to extract the projectile net-baryon distribution. We use the same approach as described in Ref. [10], where the target contribution at positive rapidity region is estimated as the average of two different rapidity dependences : (1) a simple exponential form $\exp(-y)$ [5] and (2) a gluon junction motivated form $\exp(-\frac{y}{2})$ [12]. For a symmetrical colliding system, the projectile baryons should comprise half of the whole net-baryons at mid-rapidity, the subtraction of the target contribution based on the phenomenological functions

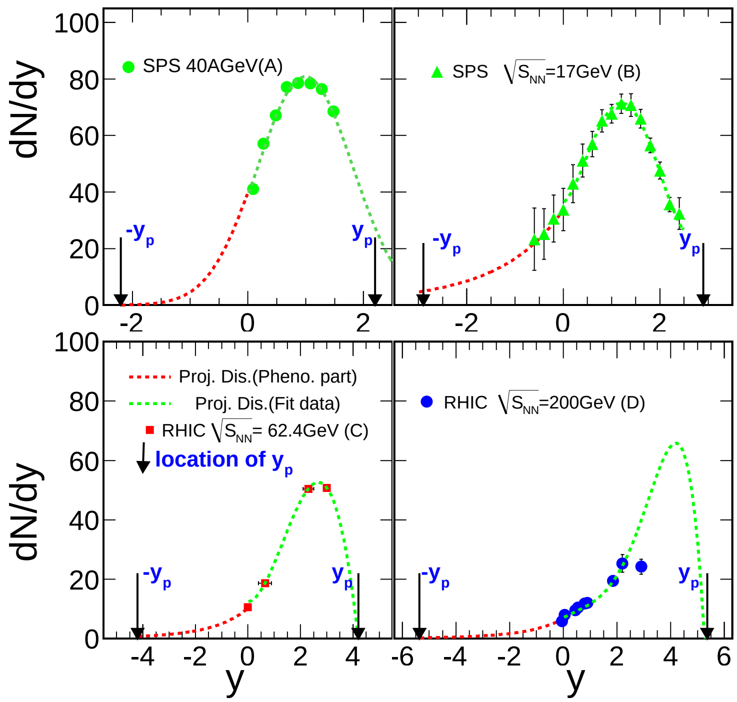

Figure 1. The projectile net-baryon rapidity distribution in the center-of-mass system. The red dashed lines indicate the projectile contribution at target rapidity region. The data points show the resulted projectile baryon density after subtracting phenomenologically the target contribution from the experimental measured net-baryon data at positive rapidity region. The green dashed lines are curves used to fit the data points. The arrows indicate the values of the beam rapidities. Panel (A), (B), (C) and (D) correspond respectively to the most central heavy-ion (Pb+Pb or Au+Au) collisions at SPS with beam energy of 40 AGeV [11], SPS at $\sqrt{s_{NN}} = 17$ GeV [8], RHIC at $\sqrt{s_{NN}} = 62.4$ GeV [10], and RHIC at $\sqrt{s_{NN}} = 200$ GeV [9].

is therefore constrained by the net-baryon measurements at mid-rapidity. At AGS energies, as there is a non-negligible target contribution around y_p, the double gaussians form used in Ref. [7] is found to be one of the best forms to describe the experimental net-baryon data and thus we will adopt their results on rapidity losses when we discuss on the energy dependence in the following section.

In Fig. 1 the data points represent the resulted projectile baryon densities after phenomenologically subtracting the target contribution from the experimental measured net-baryon data at positive rapidity region. The green dashed lines are curves used to fit the data points considering the conservation of baryon number as discussed below. The arrows indicate the values of beam rapidities. Panel (A), (B), (C) and (D) correspond to the most central heavy-ion (Pb+Pb or Au+Au) collisions at SPS with beam energy of 40 AGeV [11], SPS at $\sqrt{s_{NN}} = 17$ GeV [8], RHIC at $\sqrt{s_{NN}} = 62.4$ GeV [10], and RHIC at $\sqrt{s_{NN}} = 200$ GeV [9], respectively. Due to the projectile-target symmetry, the projectile baryon distribution at negative rapidity region should be the same as the target contribution at the positive rapidity region. These two together should form an

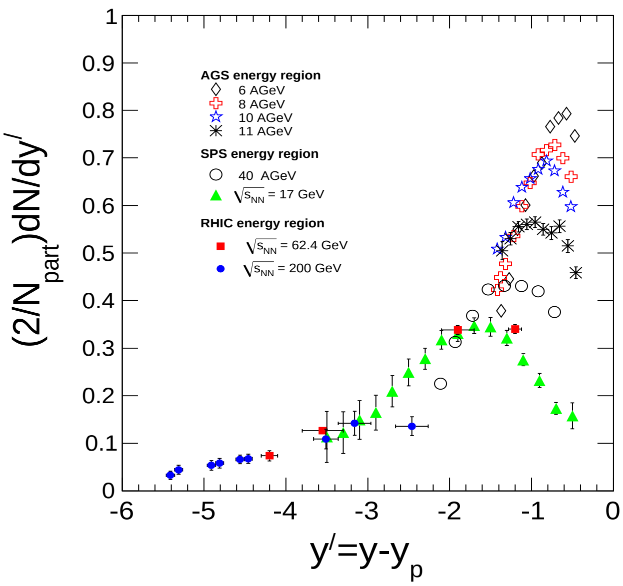

Figure 2. Normalized projectile net-baryon rapidity density $\frac{2}{N_{part}}\frac{dN^{B-\bar{B}}}{dy'}$ from AGS, SPS to RHIC energies in the frame of projectile.

even function in the center-of-mass system. In the figure the projectile contribution at negative rapidity region is indicated with red dashed lines. Thus, merging the red and green dashed lines at mid-rapidity gives the net-baryon distribution from projectile only in the whole rapidity range from $-y_p$ to y_p. It is worthwhile to mention that, in order to conserve the baryon number, the fit to the data points was done in such a manner that the total baryon number obtained by integrating the projectile net-baryon distribution from $-y_p$ to y_p amounts to half of the number of participating baryons.

To compare the projectile net-baryon distributions at different energies, Fig. 2 depicts a compilation of the projectile net-baryon rapidity density normalized to the number of participants, $\frac{2}{N_{part}}\frac{dN^{B-\bar{B}}}{dy'}$, from AGS, SPS to RHIC energies in the rapidity frame of the projectile, $y' = y - y_p$. It is evident that the rapidity distribution peaks at lower y' values with higher colliding energies from AGS to top SPS energy. This indicates the mean rapidity loss increases with beam energy. However, the peak position at RHIC energy of $\sqrt{s_{NN}} = 62.4$ GeV does not show a significant difference from that at $\sqrt{s_{NN}} = 17$ GeV, implying a possible different mechanism of baryon transport and nuclear reaction [13, 14, 15] above the top SPS energy compared to lower energies.

3. The energy dependence of rapidity loss

With the projectile net-baryon distribution as shown in Fig. 1, we can calculate the rapidity losses at SPS and RHIC energies by using Eq. (1) and Eq. (2). The results are shown as open symbols in Fig. 3 and compared to the published ones in Ref. [10],

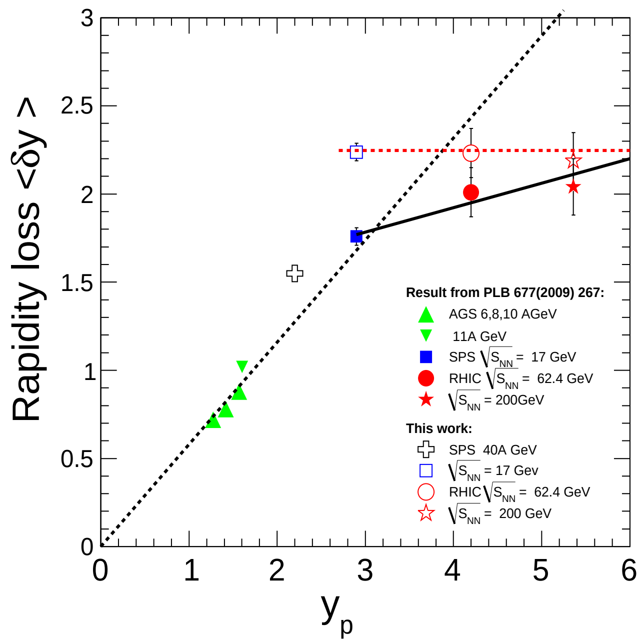

Figure 3. Rapidity losses in the most central heavy-ion (Au, Pb) collisions from AGS, SPS to RHIC as a function of beam rapidity. The black dashed line is a linear fit to the AGS energy rapidity loss as discussed in Ref. [6], while the red dashed horizontal line is used to guide your eyes. The filled symbols are results published in ref. [10] and open symbols are results from this work.

in which the target contribution was not subtracted and the $< y_b >$ was evaluated from mid-rapidity to beam rapidity. It is evident that the correction on the rapidity loss value is largest at SPS energy and decreases with energy because both the target contribution at positive rapidity and the projectile contribution at negative rapidity to the net-baryon distribution decreases with increase of energy. As a comparison to previous results, another significant feature of our results is that the rapidity loss does not increase with energy above $\sqrt{s_{NN}} = 17$ GeV. This would indicate that the reported results in Ref. [10] on the beam rapidity dependence of the rapidity loss can be misleading because the true rapidity loss value depends strongly on the target contribution to the net-baryon distribution at positive rapidity region. As the target contribution decreases with increase of energy, one would expect the target contribution to become negligible at LHC energy. Thus, it is very interesting to measure the rapidity loss value at LHC to examine the systematic trends of rapidity losses at high energies.

To explore the energy dependence of the nuclear stopping power, Fig. 4 depicts the relative rapidity loss as a function of the collision energy in the center-of-mass system. The relative rapidity loss shows an increase with energy from AGS to SPS but then a decrease above SPS energy, indicating that the largest stopping power is achievable around the top SPS energy.

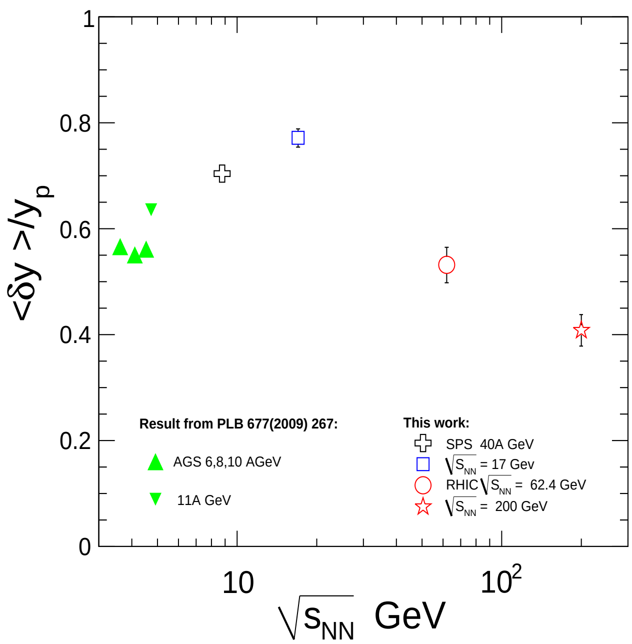

Figure 4. The relative mean rapidity loss as a function of the colliding energy in the center-of-mass system.

4. Conclusions

In this paper, we investigate a possible correction to the published results of rapidity loss by extracting the projectile net-baryon distribution in the whole rapidity range from the experimental measurements of net-baryon distribution with help of phenomenological models on the target contribution to the net-baryon density at positive rapidity. This energy dependent correction leads to a different rapidity dependence of the mean rapidity loss compared to the results reported in Ref. [10]. The mean rapidity loss starts to saturate at energy of $\sqrt{s_{NN}} = 17$ GeV and the largest stopping power is reached at the top SPS energy. This indicates that sufficiently high energy collisions will get "transparent" as assumed by Bjorken [16] and will result in approximately net-baryon-free region at mid-rapidity. As the target contribution to the net-baryon density at positive rapidity region is expected to be negligible at LHC energies, we propose to measure the rapidity loss at LHC energies so as to verify or falsify the systematic trends of the beam rapidity dependence of the rapidity loss as observed in this paper. This measurement can also help to distinguish between different proposed phenomenological mechanisms of initial coherent multiple interactions and baryon transport in heavy-ion collisions at various beam energies [5, 12].

Acknowledgments

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